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TD-03-049
November 12, 2003

Superconducting Multipole Corrector for BTeV

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Large number of different superconducting correctors were designed and manufactured for Tevatron [1,2], UNK [3], RHIC [4], LHC [5]. Some correctors showed rather low mechanical stability, long training history and usually worked at 30-50% of short sample current limit. One of the problems is how to wind the shell type multiturn coil from 0.3-0.5 mm diameter superconductor without shorts and with specified geometry. BNL for RHIC used the 5-axis computer controlled machine, which provided proper conductor positioning and fixation on separate support cylinders for each winding. Nevertheless, the field quality in RHIC shell type multipole corrector was b_1<0.6%, b_3 and b_4<2% only. But such technology very difficult to use for multilayer coils. CERN for LHC used a ribbon type cable with the number of splices to connect all ribbon wires in series. In this case the field quality will be influenced by not proper radial positioning of outer windings.

New superconducting correctors for BTeV should have parameters shown in Table 1.

Table 1

Type	Location	Trims	Integrated strength	Cold mass length
A	B49/C11	HD and VD Skew quadrupole	0.48 T*m 7.5 T	≤ 0.8 m
B	B48/C12, B47/C13	HD or VD Skew quadrupole	0.48 T*m 7.5 T	≤ 0.8 m
C	B44/C16, B43/C11	HD or VD Quadrupole Sextupole	0.48 T*m 25 T 450 T/m	≤ 1.2 m

The main difference in BTeV case is that there will be only small quantity (~12) correctors and the amount of superconductor has a very low influence on the total cost. At the same time the magnet reliability, low manufacturing cost of identical magnets with simple tooling is a preferable way of magnet optimization.

From this point of view the novel combined function multipole corrector (see Fig. 1 and Table 2) should be taken under consideration. This corrector assembled from 12 identical racetrack type coils. All these coils are powered from separate power supplies and capable generate all types of superimposed dipole, quadrupole and sextupole fields. In the case of normal dipole, quadrupole and sextupole (Type C) the total field is symmetrical relatively the median plane and there will be only 5 powered separately windings. Such corrector is also very efficient to replace the combination of normal and skew fields by the main field, which is rotated by powering different coils. The racetrack coil winding is very simple for manufacturing process. There are no problems to wind the coils with tension and provide prestress by using the aluminum shell shrinkage, which will press the coil to the low carbon steel core. The coil ends are very short and corrector is very effective in longitudinal direction. Such type of magnet can be assembled from 12 identical coil blocks and each of them can be separately tested in small test cryostat with inner bore diameter 120 mm and length 1.2 m. The magnet cold mass can be easily repaired just by replacing the bad coil. There are only joints to the current leads and it increase the magnet reliability. It looks like that this corrector will need 2 times more superconductor than the shell type design. But proper comparison showed that the superconductor volume increase not so large because of more efficient combined function overlapping fields and lower maximum fields than for correctors distributed in longitudinal direction.

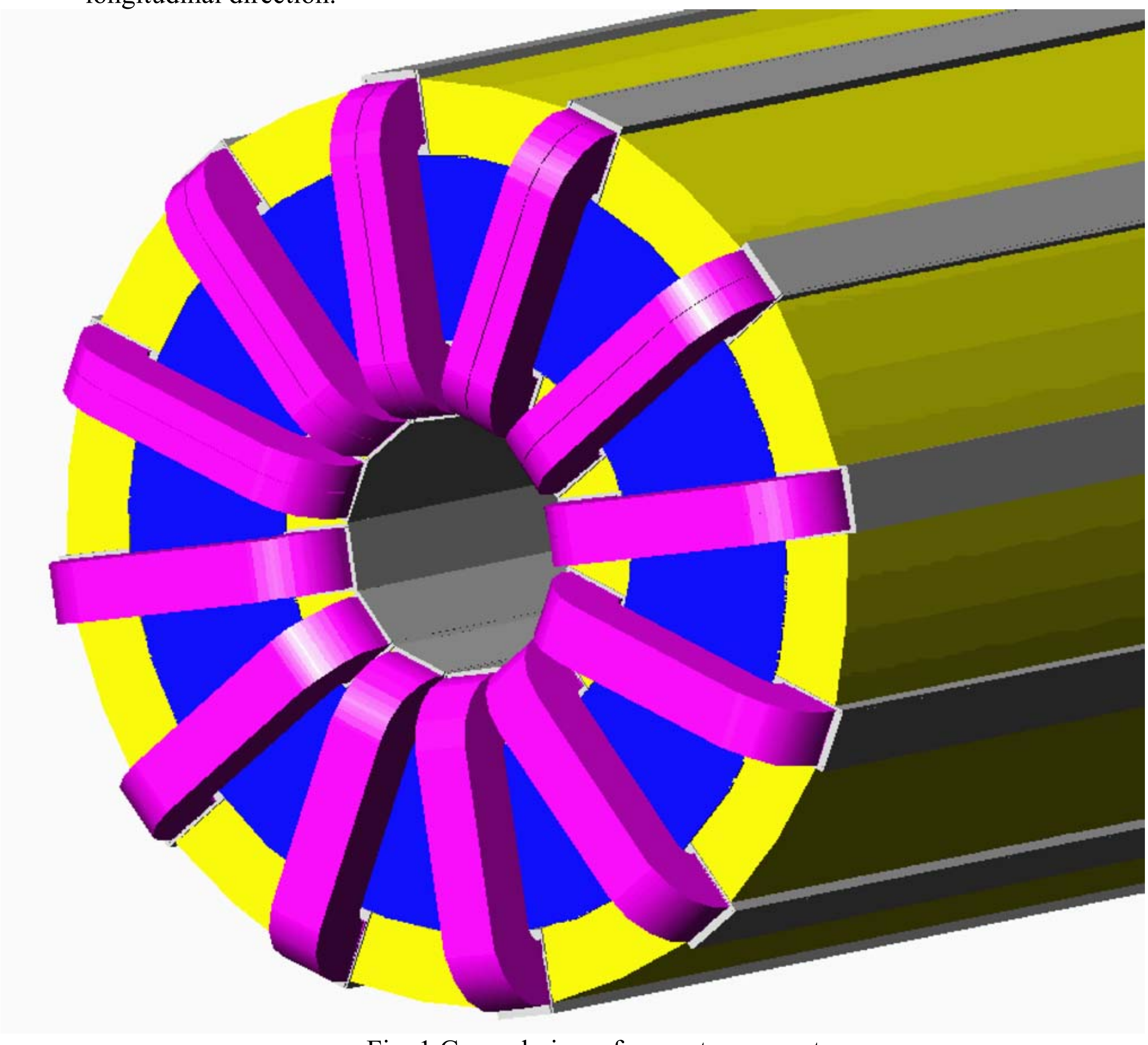

Fig. 1 General view of corrector magnet

The corrector main parameters are:

Table 2

Corrector type	A	B	C
Integrated dipole field, T*m	0.48		
Integrated quadrupole gradient, T	25		
Integrated sextupole strength , T/m	450		
Effective length, m	0.8	0.8	1.2
Inner coil radius, mm	40		
Inner core radius, mm	63		
Outer core radius, mm	120		
Operational current, A	35 - 77		
Coil number of turns	760 - 1700		
Bare strand diameter, mm	0.3 - 0.5		
Max strand diameter with insulation, mm	0.43 - 0.63		
Coil area, mm^2	368		
Cold mass outer diameter, mm	300		

1. Corrector Magnetic Design

The magnet has simple magnetic design. The combined function magnetic field is formed by 12 identical racetrack coils equally distributed with angular separation 30^o.
The number of coils is chosen to provide the dipole, quadrupole and sextupole fields at minimum number of coils. The rectangular cross-section was chosen to simplify the winding process. In common case each coil can be powered separately from 50-80 A maximum current power supply. Usually correctors have reduced demands to the field quality because the corrector field errors can produce only second order effects. A proper programming of power supplies can eliminate also all field deviations caused by manufacturing tolerances, iron saturation effects, etc.

The outer coil sections will produce the fringing field, which can be eliminated by 10mm thick magnetic shield. This shield can be also combined with the cryostat vacuum shell (see Fig. 7).

Another attractive option is to use these correctors as staying alone dipole or quadrupole or sextupole. The maximum magnet strength is limited by the iron core saturation. For example the dipole field can be easily increased with 50 A current in about 2.5 times at zero sextupole and quadrupole fields.

1.1 Corrector Type-A

This corrector should generate horizontal and vertical 0.48 T*m dipole fields with the additional 7.5 T skew quadrupole. The corrector parameters are shown in Table 3 and on Fig. 2 – Fig. 9 .

Table 3

Dipole field, T	0.6
Effective length, m	0.8
Dipole component ampere-turns, A	$Iw_{d1} = 15200$, $Iw_{d2} = 13300$, $Iw_{d3} = 7600$
Skew quadrupole gradient, T/m	9.375
Quadrupole component ampere-turns, A	$Iw_q = 12100$
Total coil ampere-turns at max field, A	33000
Maximum flux density in the yoke at max field, T	2.3

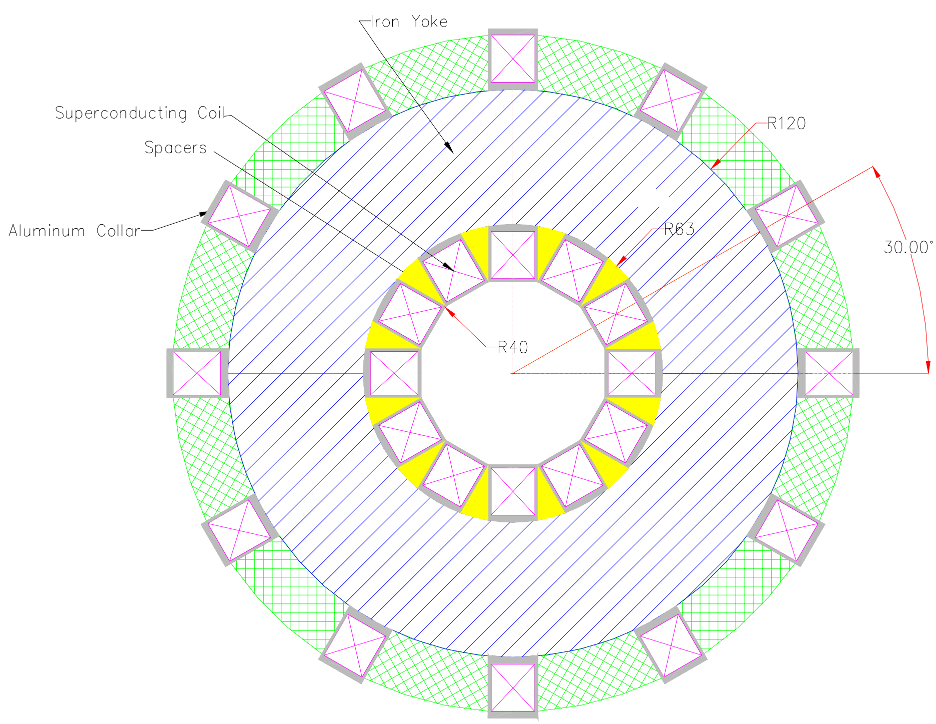

Fig. 2 Corrector A and B cross-section

No	Ncon	Radius/X	Phi/Y	Alpha/Inc	Current	CondName	N1	N2
1	1	40	0	0	7600	BTEVCOR1	20	20
2	1	39.241	12.0325	30	13300	BTEVCOR	20	20
3	1	27.967	30.041	60	7600	BTEVCOR	20	20

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ERROR OF HARMONIC ANALYSIS OF Br AT RADIUS      25.40 mm
SUM (Br(p) - SUM (An cos(np) + Bn sin(np)))   0.1186E-04


MAXIMUM ABSOLUTE FIELD ERROR (T)
MAX (BrN - SUM (An cos(np) + Bn sin(np)))     0.5036E-03

MAIN FIELD:     -0.59781 NORMAL REL. MULTIPOLES (1.D-4):
b 1:  10000.00000  b 2:       0.00000  b 3:      -0.07739
b 4:        0.00000  b 5:      -2.36804  b 6:       0.00000
b 7:       -0.57585  b 8:       0.00000  b 9:      -0.00717
b10:        0.00000  b11:       5.45918  b12:       0.00000
b13:        0.97742  b14:       0.00000  b15:       0.00011
b16:        0.00000  b17:       0.00027  b18:       0.00000
b19:        0.00019  b20:       0.00000  b

NI/B :    -0.953E+05
```

Fig. 3 Dipole geometry and field harmonics (Dip1rot.data)

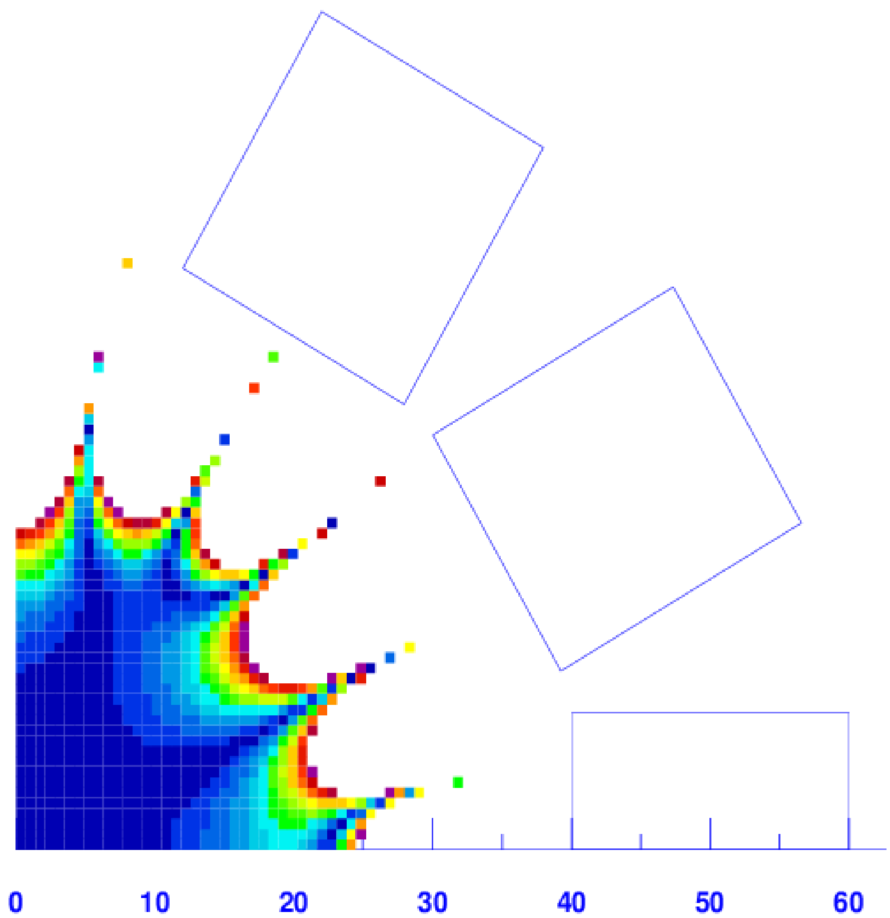

Fig. 4 Dipole field homogeneity

No	Ncon	Radius/X	Phi/Y	Alpha/Inc	Current	CondName	N1	N2
1	1	40	-9.2	0	15200	CORR1	10	10
2	1	39.241	12.0325	30	33000	CORR1	10	10
3	1	27.967	30.041	60	33000	CORR1	10	10
4	1	9.2	40	90	15200	CORR1	10	10
5	1	-12.0325	39.241	120	-6400	CORR1	10	10
6	1	-30.041	27.967	150	-17800	CORR1	10	10
7	1	-40	9.2	180	-15200	CORR1	10	10
8	1	-39.241	-12.0325	210	-8800	CORR1	10	10
9	1	-27.967	-30.041	240	-8800	CORR1	10	10
10	1	-9.2	-40	270	-15200	CORR1	10	10
11	1	12.0325	-39.241	300	-17800	CORR1	10	10
12	1	30.041	-27.967	330	-6400	CORR1	10	10

Fig. 5 Corrector A geometry and coil ampere-turns at maximum combined field

```
ERROR OF HARMONIC ANALYSIS OF Br AT RADIUS     25.40 mm
SUM (Br(p) - SUM (An cos(np) + Bn sin(np)))  0.2296E-04

MAXIMUM ABSOLUTE FIELD ERROR (T)
MAX (BrN - SUM (An cos(np) + Bn sin(np)))    0.8355E+00

MAIN FIELD:    -0.59781 NORMAL REL. MULTIPOLES (1.D-4):
b 1:  10000.00000  b 2:     -0.02913  b 3:      0.00099
b 4:      0.00000  b 5:     -2.32043  b 6:      0.00221
b 7:     -0.55706  b 8:      0.00000  b 9:     -0.00070
b10:      0.00021  b11:      5.45721  b12:      0.00000
b13:      0.97713  b14:     -0.00001  b15:      0.00000
b16:      0.00000  b17:      0.00016  b18:      0.00000
b19:      0.00013  b20:      0.00000  b

                         SKEW  REL. MULTIPOLES (1.D-4):
a 1: -10000.04258  a 2: -3992.24722  a 3:      0.02127
a 4:      0.00000  a 5:      2.32912  a 6:     -0.00572
a 7:     -0.55691  a 8:      0.00000  a 9:      0.00071
a10:     10.88396  a11:      5.45699  a12:      0.00000
a13:     -0.97717  a14:     -0.31966  a15:      0.00000
a16:      0.00000  a17:     -0.00017  a18:      0.00000
a19:      0.00013  a20:      0.00000  a

NI/B :   -0.161E+06
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Fig. 6 Corrector A field harmonics (DQS1rot.data)

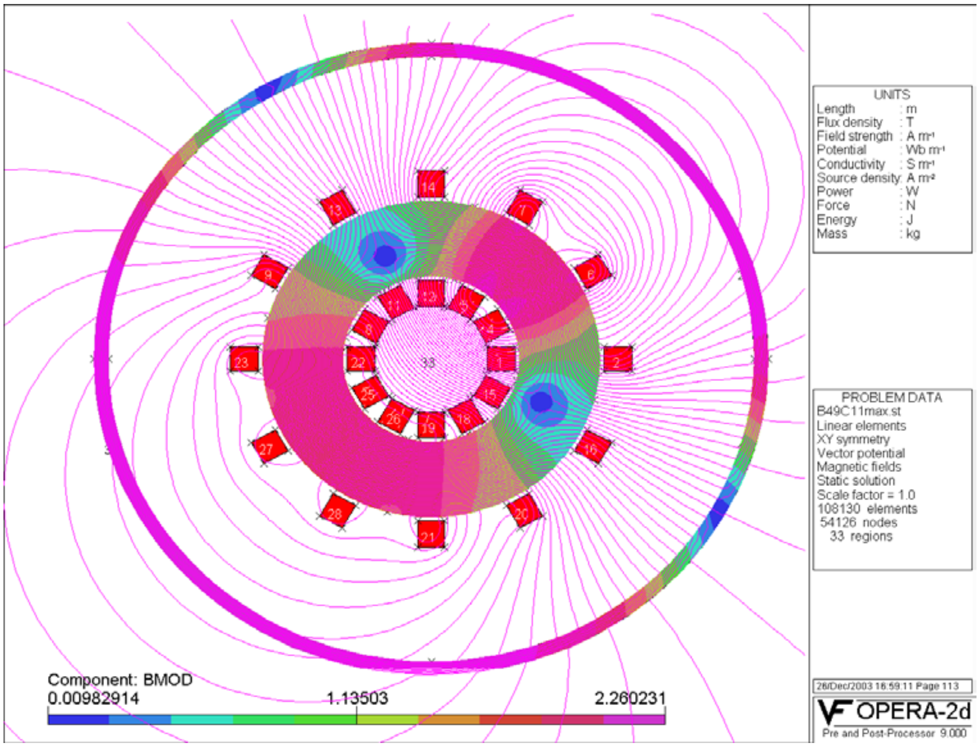

Fig. 7 Corrector A flux density distribution

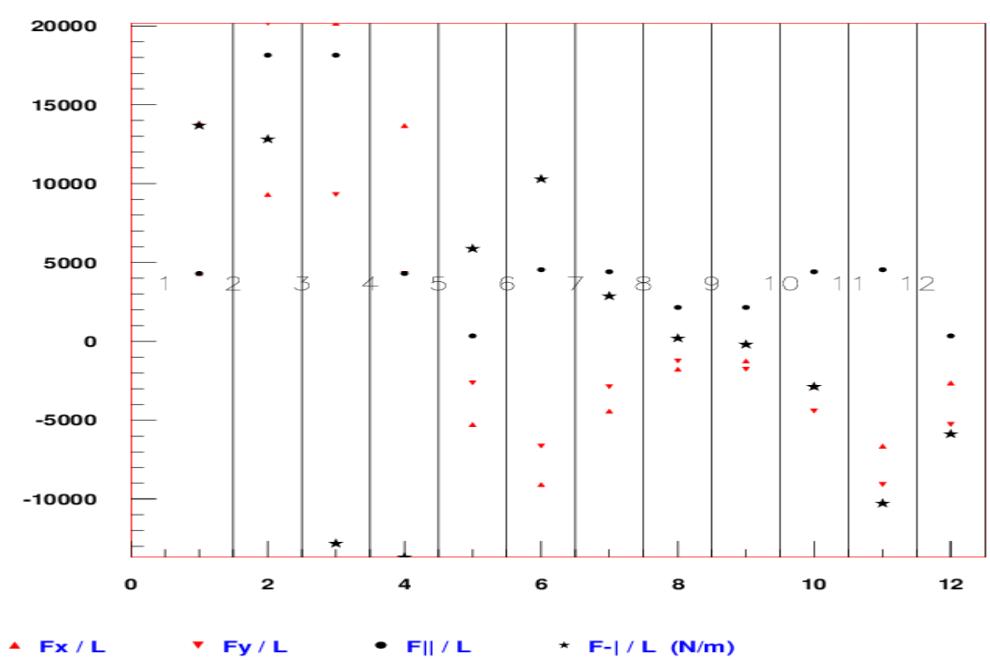

Fig. 8 Magnetic forces in Type A correctors

Maximal magnetic force applied to the coils N2 and N3 and equal 1754 kg for 0.8 m length magnet.

The electrical connections are very simple for this type of magnet. Each coil should be connected to pair of current leads capable to carry up to 80 A current. Individual bipolar power supplies should power all current leads outer connectors. The coil current is the sum of all components, which produce the dipole and quadrupole fields. The coil currents for Fig. 9 diagram are:

$$\mathbf{I_1 = I_{v1}} \qquad \mathbf{I_7 = - I_1}$$
$$\mathbf{I_2 = I_{v2} + I_{h3} + I_{sq}}$$
$$\mathbf{I_3 = I_{v3} + I_{h2} + I_{sq}}$$
$$\mathbf{I_4 = I_{h1}} \qquad \mathbf{I_{10} = -I_4}$$
$$\mathbf{I_5 = -I_{v3} + I_{h2} - I_{sq}}$$
$$\mathbf{I_6 = -I_{v2} + I_{h3} - I_{sq}}$$
$$\mathbf{I_8 = -I_{v2} - I_{h3} + I_{sq}}$$
$$\mathbf{I_9 = -I_{v3} - I_{h2} + I_{sq}}$$
$$\mathbf{I_{11} = I_{v3} - I_{h2} - I_{sq}}$$
$$\mathbf{I_{12} = I_{v2} - I_{h3} - I_{sq}}$$

The current directions for different field components are shown on Fig. 9. Skew fields can be obtained by the angular rotation of corresponding multipole ring diagram. It is also possible to generate an octupole field if add the same direction current to the coils 1-4-7-10.

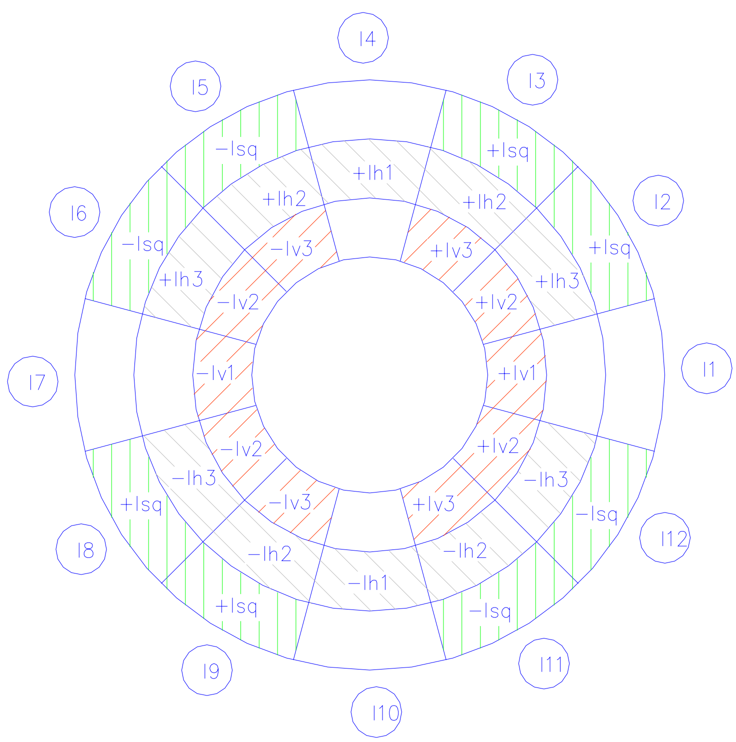

Fig. 9 Azimuthal currents distribution in corrector A, where
I_{v1}, I_{v2}, I_{v3} – vertical dipole currents
I_{h1}, I_{h2}, I_{h3} – horizontal dipole currents
I_{sq} – current of skew quadrupole

1.2 Corrector B

This corrector should generate horizontal or vertical 0.48 T*m dipole field with the additional 7.5 T skew quadrupole. All corrector parameters can be obtained from corrector A design with only one dipole field component. The corrector parameters are shown in Table 4 and on Fig. 10 – Fig. 11 .

Table 4

Dipole field, T	0.6
Effective length, m	0.8
Dipole component ampere-turns, A	$Iw_{d1} = 15200$, $Iw_{d2} = 13300$, $Iw_{d3} = 7600$
Skew quadrupole gradient, T/m	9.375
Skew quadrupole component ampere-turns,A	$Iw_q = 12100$
Total coil ampere-turns at max field, A	25400
Maximum flux density in the yoke at max field, T	2.3

The coil currents for the corrector with vertical dipole are:

$$I_1 = I_{v1} \qquad I_7 = -I_{v1} = -I_1$$
$$I_2 = I_{v2} + I_{sq} \qquad I_6 = -I_{v2} - I_{sq} = -I_2$$
$$I_3 = I_{v3} + I_{sq} \qquad I_5 = -I_{v3} - I_{sq} = -I_3$$
$$I_8 = -I_{v2} + I_{sq} \qquad I_{12} = I_{v2} - I_{sq} = -I_8$$
$$I_9 = -I_{v3} + I_{sq} \qquad I_{11} = I_{v3} - I_{sq} = -I_9$$
$$I_4 = 0$$
$$I_{10} = 0$$

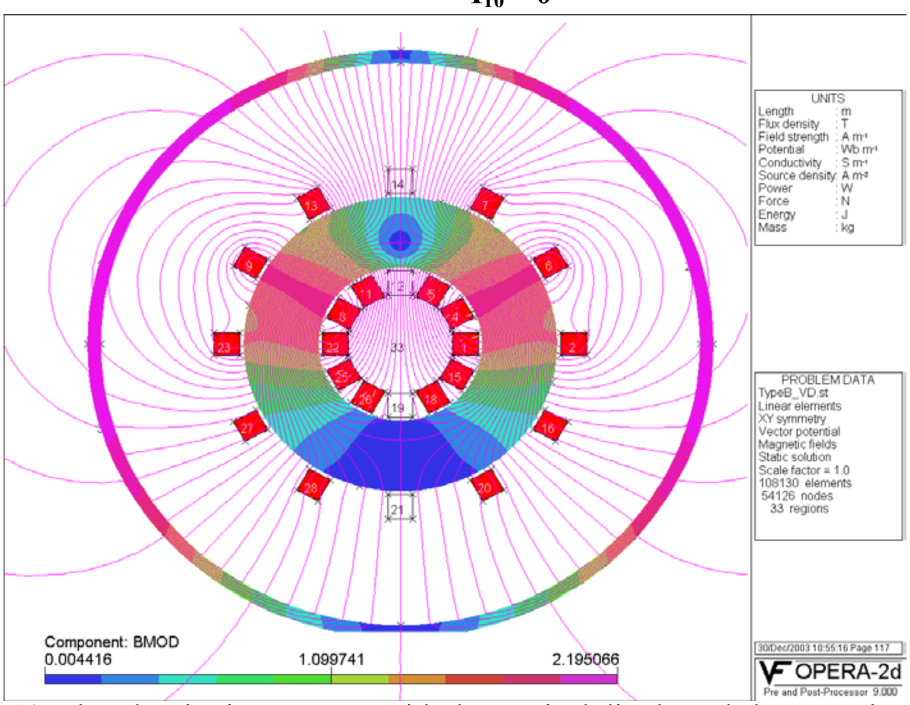

Fig. 10 Flux density in corrector with the vertical dipole and skew quadrupole

The coil currents for the corrector with horizontal dipole are:

$$I_2 = I_{h3} + I_{sq} \qquad I_{12} = -I_{h3} - I_{sq} = -I_2$$
$$I_3 = I_{h2} + I_{sq} \qquad I_{11} = -I_{h2} - I_{sq} = -I_3$$
$$I_4 = I_{h1} \qquad I_{10} = -I_{h1} = -I_4$$
$$I_5 = I_{h2} - I_{sq} \qquad I_9 = -I_{h2} + I_{sq} = -I_5$$
$$I_6 = I_{h3} - I_{sq} \qquad I_8 = -I_{h3} + I_{sq} = -I_6$$
$$I_1 = 0$$
$$I_7 = 0$$

This type corrector is powered by 5 independent power supplies.

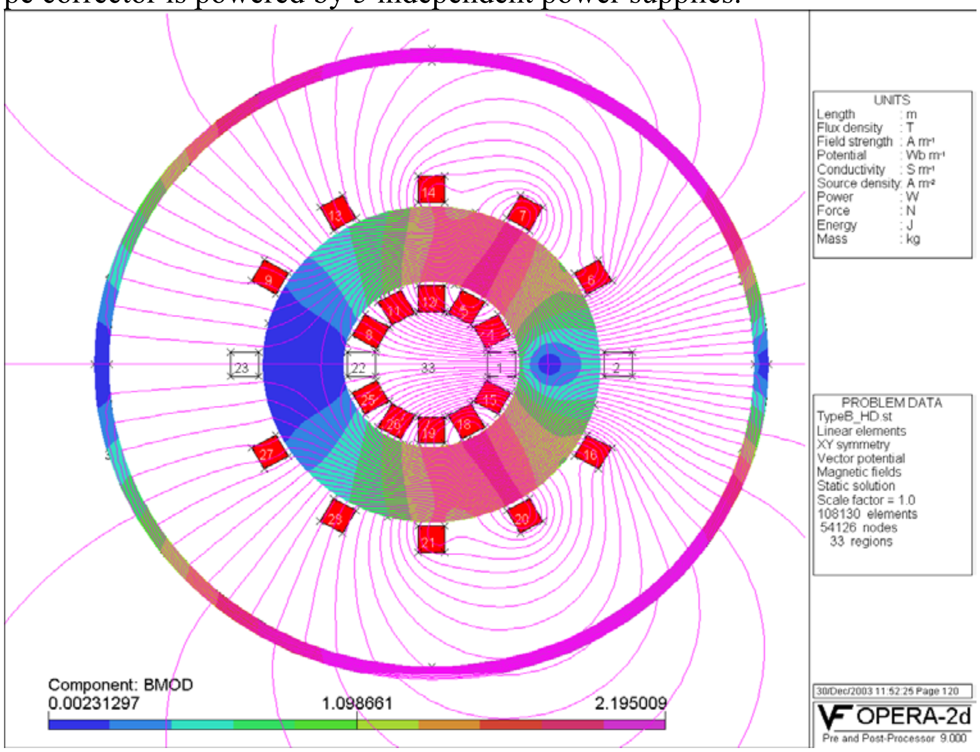

Fig. 11 Flux density in corrector with the horizontal dipole and skew quadrupole

1.3 Corrector C

This corrector should generate horizontal or vertical 0.48 T*m dipole field with the additional 25 T quadrupole and 450 T/m sextupole. The corrector parameters are shown in Table 5 and on Fig. 12 – Fig. 1X . The cold mass assembly is rotated on 15º as shown on Fig. 12. The magnet design is the same as for A and B correctors. Magnetic field, currents and forces are symmetrical relatively magnet median plane, that is why only 5 independent power supplies needed to power this corrector.

Table 5

Dipole field, T	0.4
Effective length, m	1.2
Dipole component ampere-turns, A	Iw_{d1} = 9856.2, Iw_{d2} = 7189, Iw_{d3} = 2650.9
Quadrupole gradient, T/m	20.833
Quadrupole component ampere-turns, A	Iw_q= 26828
Sextupole strength, T/m^2	375
Sextupole component ampere-turns, A	21728.5
Total conductor current at all component max field, A	50-80
Maximum flux density in the yoke at max field, T	2.0

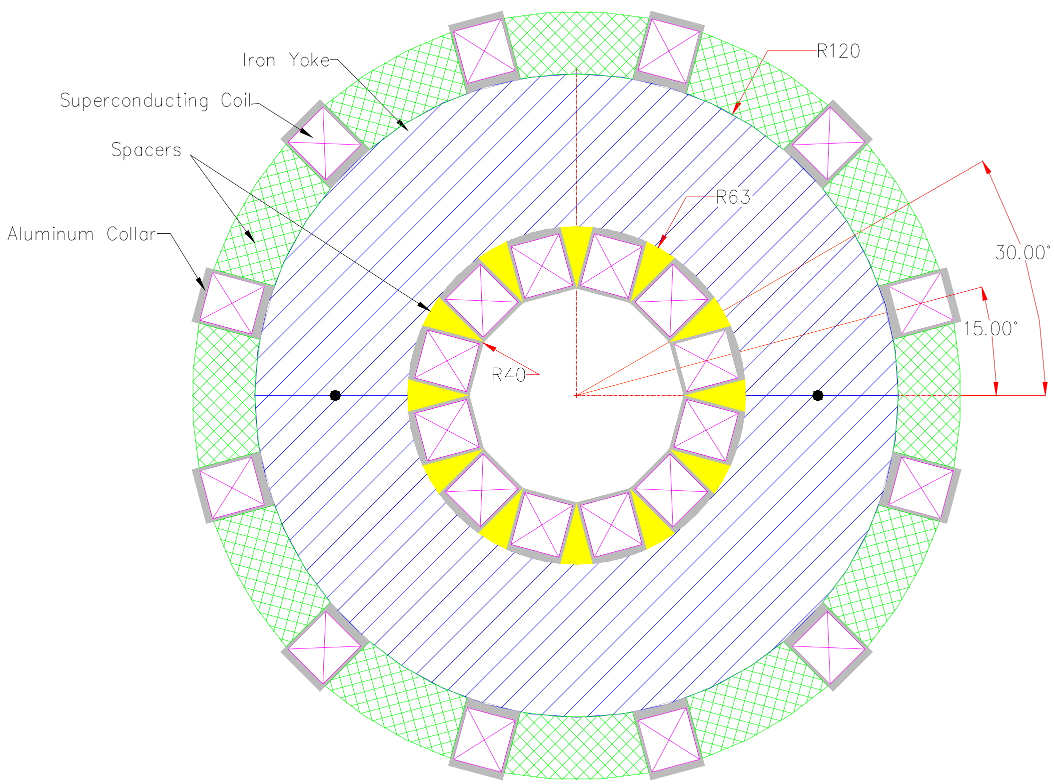

Fig. 12 Corrector C cross-section

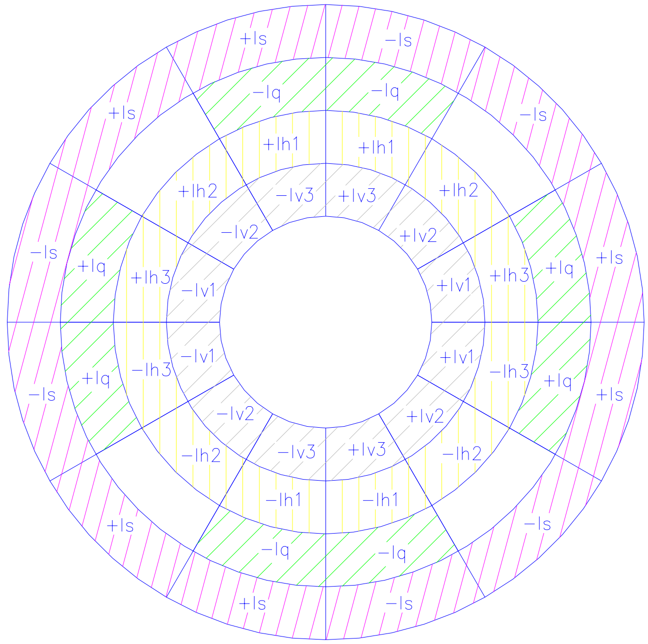

Fig. 13 Azimuthal currents distribution in C corrector, where
I_{v1}, I_{v2}, I_{v3} - vertical dipole currents,
I_{h1}, I_{h2}, I_{h3} - horizontal dipole currents,
I_q - quadrupole current,
I_s - sextupole current.

The coil currents for this corrector with vertical dipole are:

$\mathbf{I_1 = I_{12} = I_{d1} + I_q + I_s}$ $\mathbf{I_{12} = - I_1}$

$\mathbf{I_2 = I_{11} = I_{d2} - I_s}$ $\mathbf{I_{11} = - I_2}$

$\mathbf{I_3 = I_{10} = I_{d3} - I_q - I_s}$ $\mathbf{I_{10} = - I_3}$

$\mathbf{I_4 = I_9 = -I_{d3} - I_q + I_s}$ $\mathbf{I_9 = - I_4}$

$\mathbf{I_6 = I_7 = -I_{d1} + I_q - I_s}$ $\mathbf{I_7 = - I_6}$

$\mathbf{I_5 = - I_2}$

$\mathbf{I_8 = - I_5}$

No	Ncon	Radius/X	Phi/Y	Alpha/Inc	Current	CondName	N1	N2
1	1	41.0182	1.466	15	58413	BTEVCOR	20	20
2	1	34.79	21.79	45	-14540	BTEVCOR	20	20
3	1	19.239	36.256	75	-45906	BTEVCOR	20	20
4	1	-1.466	41.0182	105	-7750	BTEVCOR	20	20
5	1	-21.79	34.79	135	14540	BTEVCOR	20	20
6	1	-36.256	19.239	165	-4757	BTEVCOR	20	20
7	1	-41.0182	-1.466	195	-4757	BTEVCOR	20	20
8	1	-34.79	-21.79	225	14540	BTEVCOR	20	20
9	1	-19.239	-36.256	255	-7750	BTEVCOR	20	20
10	1	1.466	-41.0182	285	-45906	BTEVCOR	20	20
11	1	21.79	-34.79	315	-14540	BTEVCOR	20	20
12	1	36.256	-19.239	345	58413	BTEVCOR	20	20

```
ERROR OF HARMONIC ANALYSIS OF Br AT RADIUS      25.40 mm
SUM (Br(p) - SUM (An cos(np) + Bn sin(np)))   0.7432E-04

MAXIMUM ABSOLUTE FIELD ERROR (T)
MAX (BrN - SUM (An cos(np) + Bn sin(np)))     0.7326E+00

MAIN FIELD:     -0.39884 NORMAL REL. MULTIPOLES (1.D-4):
b 1:  10000.00000  b 2:  13267.87286  b 3:   6003.10682
b 4:      0.00000  b 5:      0.66167  b 6:      0.02465
b 7:     -0.11591  b 8:      0.00000  b 9:    -76.02892
b10:    -36.19108  b11:     -5.46565  b12:      0.00000
b13:     -0.97866  b14:     -1.06235  b15:     -0.26914
b16:      0.00000  b17:     -0.00005  b18:      0.00002
b19:      0.00003  b20:      0.00000  b
```

Fig. 14 Corrector (with vertical dipole) geometry, currents and harmonics

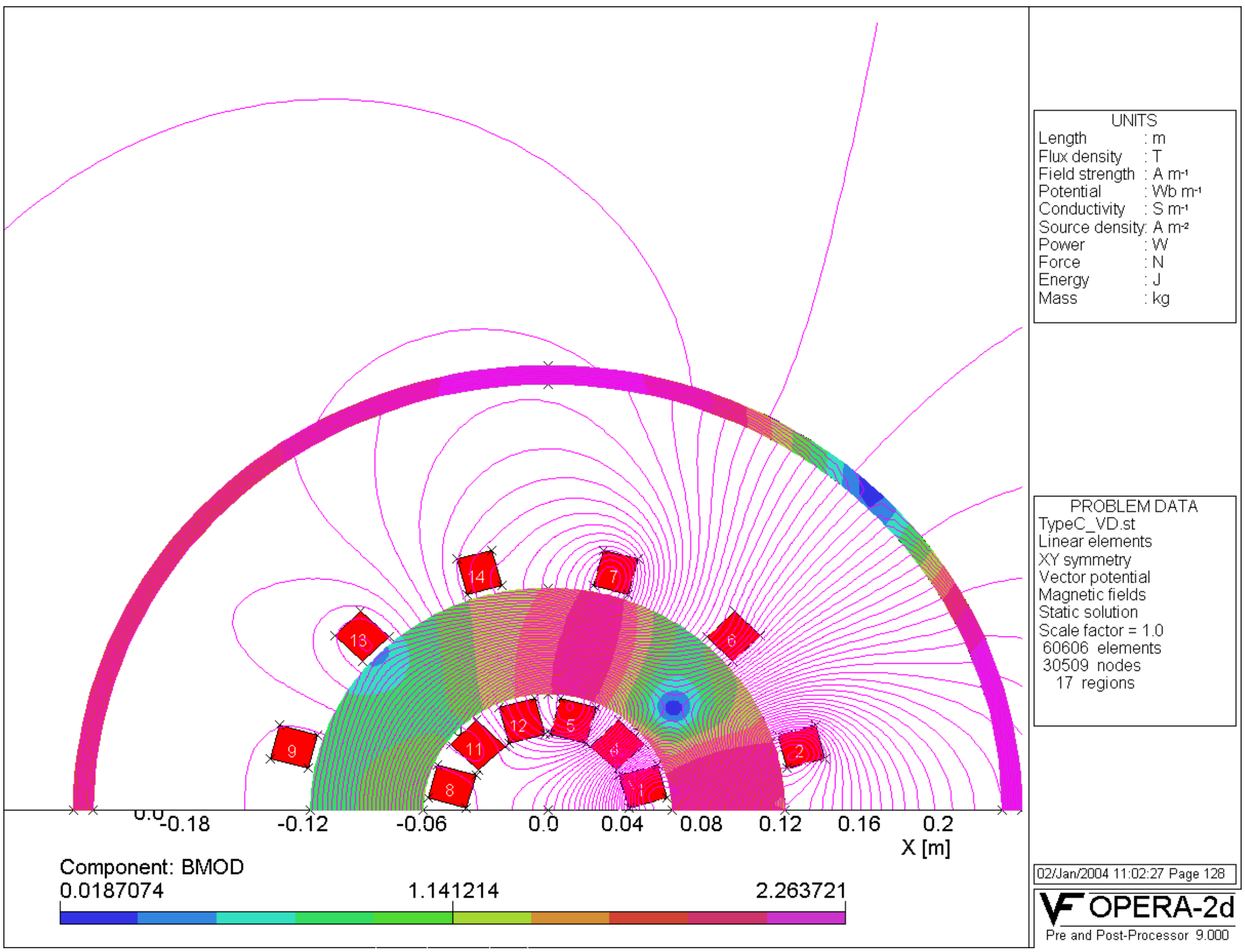

Fig. 15 Corrector C flux density distribution at max currents

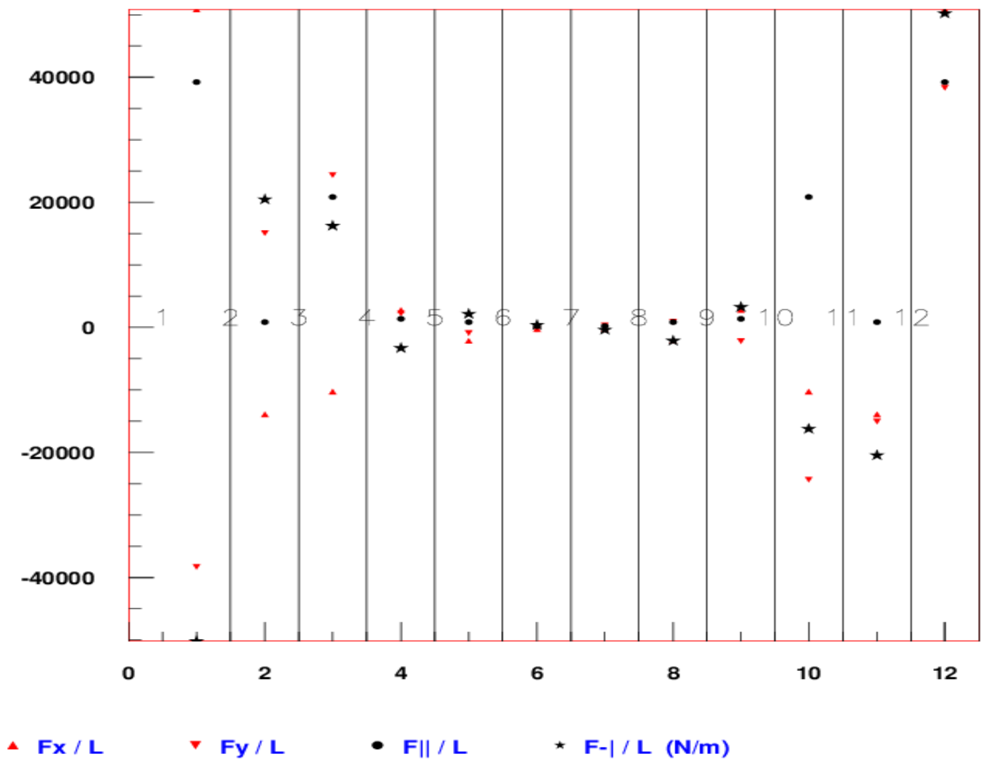

Fig. 16 Corrector C (with vertical dipole) magnetic forces

No	Ncon	Radius/X	Phi/Y	Alpha/Inc	Current	CondName	N1	N2
1	1	41.0182	1.466	15	51207	BTEVCOR	20	20
2	1	34.79	21.79	45	-14540	BTEVCOR	20	20
3	1	19.239	36.256	75	-38700	BTEVCOR	20	20
4	1	-1.466	41.0182	105	4757	BTEVCOR	20	20
5	1	-21.79	34.79	135	28918	BTEVCOR	20	20
6	1	-36.256	19.239	165	7750	BTEVCOR	20	20
7	1	-41.0182	-1.466	195	2449	BTEVCOR	20	20
8	1	-34.79	-21.79	225	14540	BTEVCOR	20	20
9	1	-19.239	-36.256	255	-14956	BTEVCOR	20	20
10	1	1.466	-41.0182	285	-58413	BTEVCOR	20	20
11	1	21.79	-34.79	315	-28918	BTEVCOR	20	20
12	1	36.256	-19.239	345	45906	BTEVCOR	20	20

```
ERROR OF HARMONIC ANALYSIS OF Br AT RADIUS       25.40 mm
SUM (Br(p) - SUM (An cos(np) + Bn sin(np)))    0.7447E-04

MAXIMUM ABSOLUTE FIELD ERROR (T)
MAX (BrN - SUM (An cos(np) + Bn sin(np)))      0.7328E+00

MAIN FIELD:      0.39877 NORMAL REL. MULTIPOLES (1.D-4):
b 1:        0.27205  b 2: -13270.21198  b 3:  -6002.08707
b 4:        0.00000  b 5:        0.15455  b 6:       -0.02466
b 7:       -0.15127  b 8:        0.00000  b 9:       76.02291
b10:       36.19746  b11:        0.01036  b12:        0.00000
b13:        0.00105  b14:        1.06253  b15:        0.26914
b16:        0.00000  b17:        0.00011  b18:       -0.00002
b19:       -0.00015  b20:        0.00000  b

                              SKEW  REL. MULTIPOLES (1.D-4):
a 1:  10000.00000  a 2:        0.01782  a 3:       -0.85850
a 4:        0.00000  a 5:        1.27195  a 6:        0.00236
a 7:        0.11912  a 8:        0.00000  a 9:       -0.06288
a10:       -0.00006  a11:        5.46689  a12:        0.00000
a13:       -0.97597  a14:       -0.00001  a15:        0.00009
a16:        0.00000  a17:        0.00029  a18:        0.00000
a19:       -0.00002  a20:        0.00000  a
```

Fig. 17 Corrector C (with horizontal dipole) geometry, currents and harmonics

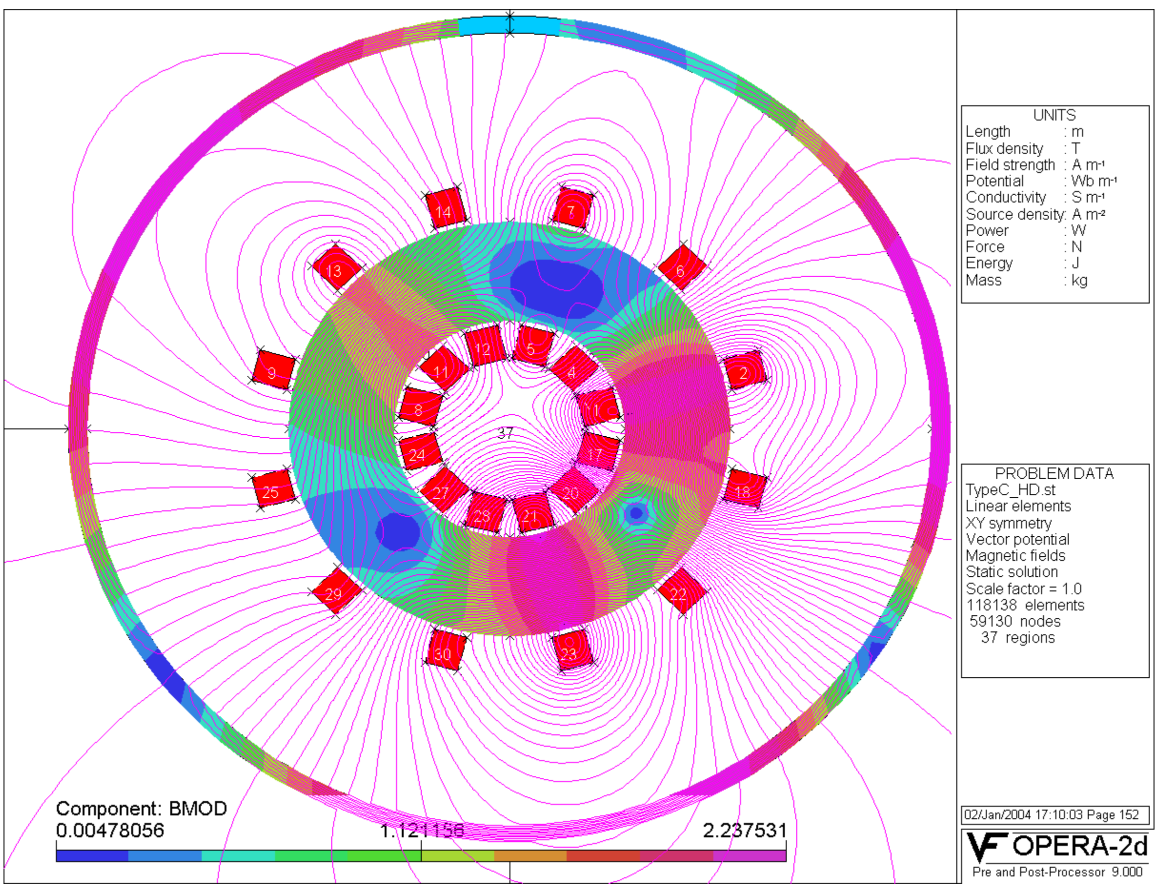

Fig. 18 Flux density distribution in Corrector C (with horizontal dipole)

2. Mechanical Design Concepts

There are at least two options of cold mass fabrication and assembly. The first one is to wind all racetrack coils separately on the aluminum or stainless steel bobbins, then assemble two sub assemblies with the 6 coils each. In this case the iron core should be splitted in the median plane. After that cold mass should be vacuum impregnated with epoxy. The second version is to split the iron core on 4 or 12 sectors and use these parts as mandrel for coil winding, impregnation and support. In this case each iron block with one coil can be tested separately. Because at all field combinations the iron blocks are tightened to each other, only positioning pins needed to provide proper block position in space. Special attention needed to provide the tight coil bobbin connection to the yoke because at some currents combination will be Lorentz forces directed inside the magnet aperture. There also some cold mass decentering forces. Decentering force for correctors A and B rather low (160 kg) and for corrector C higher (1900 kg). So, the cold mass support structure should be capable carry this load plus the magnet weight (~500kg).

Aluminum and stainless steel bobbin material should be compared. Aluminum can provide the coil prestress after cooling down but stainless steel can be welded to the iron yoke and that simplify the magnet assembly. Usual machining tolerances are acceptable and the extra machining cost will be low.

3. Electrical Circuits, Currents and Power Supplies

The electrical connections are very simple for this type of magnet. Each coil should be connected to pair of current leads capable to carry ~80 A current. Individual bipolar power supplies should power all current leads outer connectors. For example new compact power supplies were designed for TESLA Test Facility (see Fig. 20). It is possible to reduce the number of currents and power supplies to 5 in the case of normal dipole, quadrupole and sextupole fields (see Table 6).

The coil current is the sum of all components, which produce the dipole, quadrupole and sextupole fields. The current directions for different normal field components are shown on Fig. 6. Skew fields can be obtained by the angular rotation of corresponding multipole ring diagram.

Table 6

Corrector Type	Number of PS/corrector	Max coil ampere-turns	Max coil current at 760 turns/coil
A (HD+VD+SQ)	10	33000	43.4
B (VD+SQ)	5	25400	33.4
B (HD+SQ)	5	25400	33.4
C (VD+Q+S)	5	58413	76.8
C (HD+Q+S)	10	58413	76.8

The coil current can be reduced if decrease the superconducting wire diameter and proportionally increase number of turns. Conductor diameter, number of turns and max current should be simultaneously optimized with reasonable quench current margin and mechanical stability. The critical current margin is shown on Fig. 19. There is about two times difference in max currents for A,B and C magnets. It is possible to reduce the volume of superconductor for A and B correctors proportionally increasing the current.

It should be noted that at the magnet ends will be larger magnetic field and correspondingly lower current margin. This effect can be reduced by proper profiling coils and yoke at the ends.

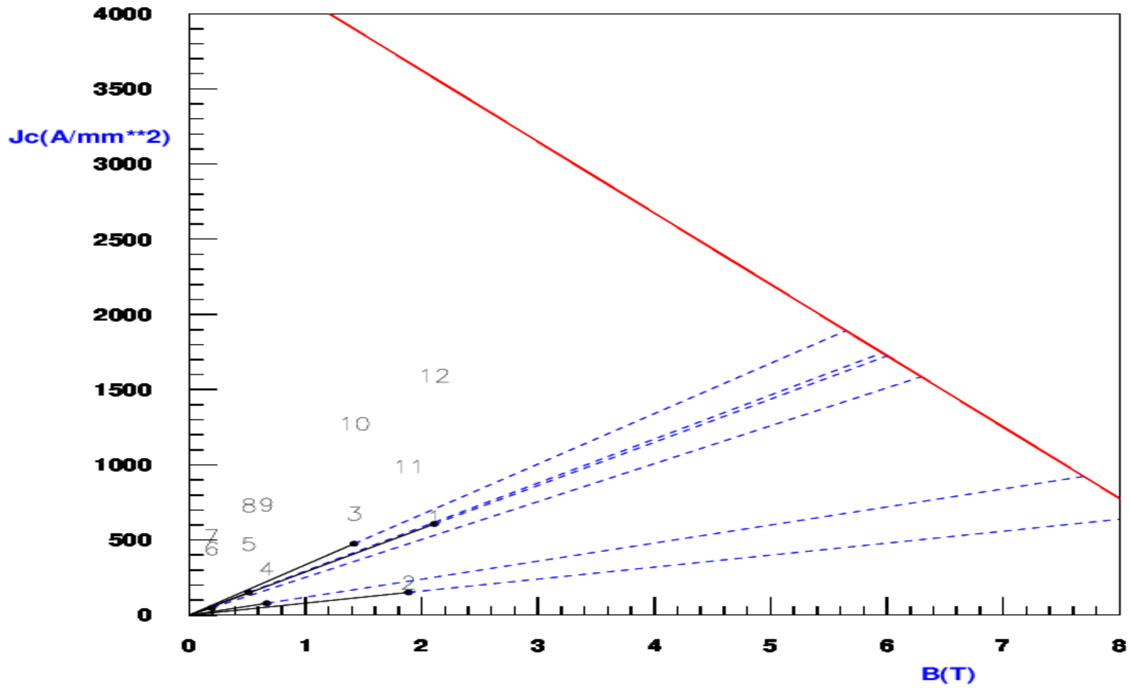

Fig. 19 Current density in different coils vs field for C corrector with vertical dipole

Fig. 20 Power supplies for TESLA Test Facility superconducting magnets

4. Multipole Corrector Failure Analysis

The possible scenarios of corrector failures and diagnostics are shown in the Table 7.

Table 7

Magnet failure and action	**Stay alone magnets (BTeV-I)**	**Tevatron corrector**	**Multipole Corrector (BTeV-II)**	**Comments**
The coil wire is broken	Zero current and zero magnet field	Zero current from one of the power supplies and zero corresponding multipole field	Zero current from one of the power supplies and zero corresponding coil field	
Actions if the wire is broken	Replace the spool or continue to work without magnet	Replace the spool or continue to work without winding	Disconnect the bad coil and reprogram the power supplies currents (automatic or manual operation)	BTeV-II nearest coils can compensate the broken coil failure with some lost in the field quality
Diagnostics	Open magnet circuit	Open winding circuit	Open group of coils circuit	Very simple detection of zero current
The coil is short-circuited and quenched	Magnet quench	Magnet quench	Magnet or only coil quench	
Diagnostics	Zero magnet current	Zero winding current	Zero group of coils current	
Actions if the coil is short-circuited and quenched	Replace the spool or continue to work without magnet	Replace the spool or continue to work without winding	Disconnect the bad coil and reprogram the power supplies currents (automatic or manual operation)	BTeV-II nearest coils can compensate the bad coil failure with some lost in the field quality

One can imagine the scenario when the group of turns is short-circuited and this coil has no quenches during the operation. This coil will produce the magnetic field distortions which will be difficult to detect during accelerator operation. This problem exists in any type of corrector magnet because eliminated turns will cause all field harmonics distortions for any type of winding. One of the ways is to check the coils inductance during shut downs and another periodically excite the coils up to the maximum current. Earlier quenches will show that there is the coil problem.

Correctors Comparison

The overview of designed and tested superconducting correctors showed that in most magnets the operating current was chosen with large margin (see Table 8). During fabrication some of the magnets failed to pass the high voltage test because of weak enamel insulation and short-circuits between turns and to the ground. Proposed BTeV variants of multipole corrector are described in [6] and in this note.

Table 8

Parameter	**FNAL**	**RHIC**	**UNK**	**LHC**	**BTEV**
Dipole field, T	0.62	0.58	0.59	0.11	0.6 max
Quadrupole gradient, T/m	9.84	2.72	4.37	60	20.8 max
Sextupole strength, T/m^2	294.5	-	448		375
Operating current, A	50	50	20	100	35-77
Critical current @ 4.2K, 5T, A	160	130	54-69	228	160
Coil maximum field, T	1.5	-	1.3	3 -3.22	1.7
Coil inner diameter, mm	80	82.1	80	90	80
Outer cold mass diameter,mm	152		168	242	290
Conductor diameter, mm	0.5	0.33	0.3	0.5	0.5
Strand current density, A/mm^2	255	585	283	510	255
Cu/NbTi ratio	-	2.5	1.7	2.0	2.0
Jc @ 4.2K, 5T, A/mm^2	-	-	2000	3165	2200
Length, m	0.77	0.5	1.37	0.52	0.8 - 1.2

The parameters of these correctors are not optimized now. These parameters should be corrected only after the prototype tests and in most defined by the magnet mechanical stability.

Summary

Proposed variant of multipole corrector has the following advantages:

- only one type of multipole magnet which cover all needs
- possibility to generate any combination of dipole, quadrupole and sextupole normal and skew fields
- stable magnetic center and field quality
- simple coil manufacturing
- only two types with 0.8 m and 1.2 m length
- no inner splices
- good mechanical stability because of eliminating opposite forces in coils
- good coil cooling
- possibility of individual coil block test and training

- simple tooling
- easy assembly, disassembly and repair
- low labor.

As a payment for all of these: more current leads and power supplies.
It seems, reasonable to manufacture and test 1/4 part of corrector with three racetrack coils (see Fig. 21) to confirm and correct if need the design.

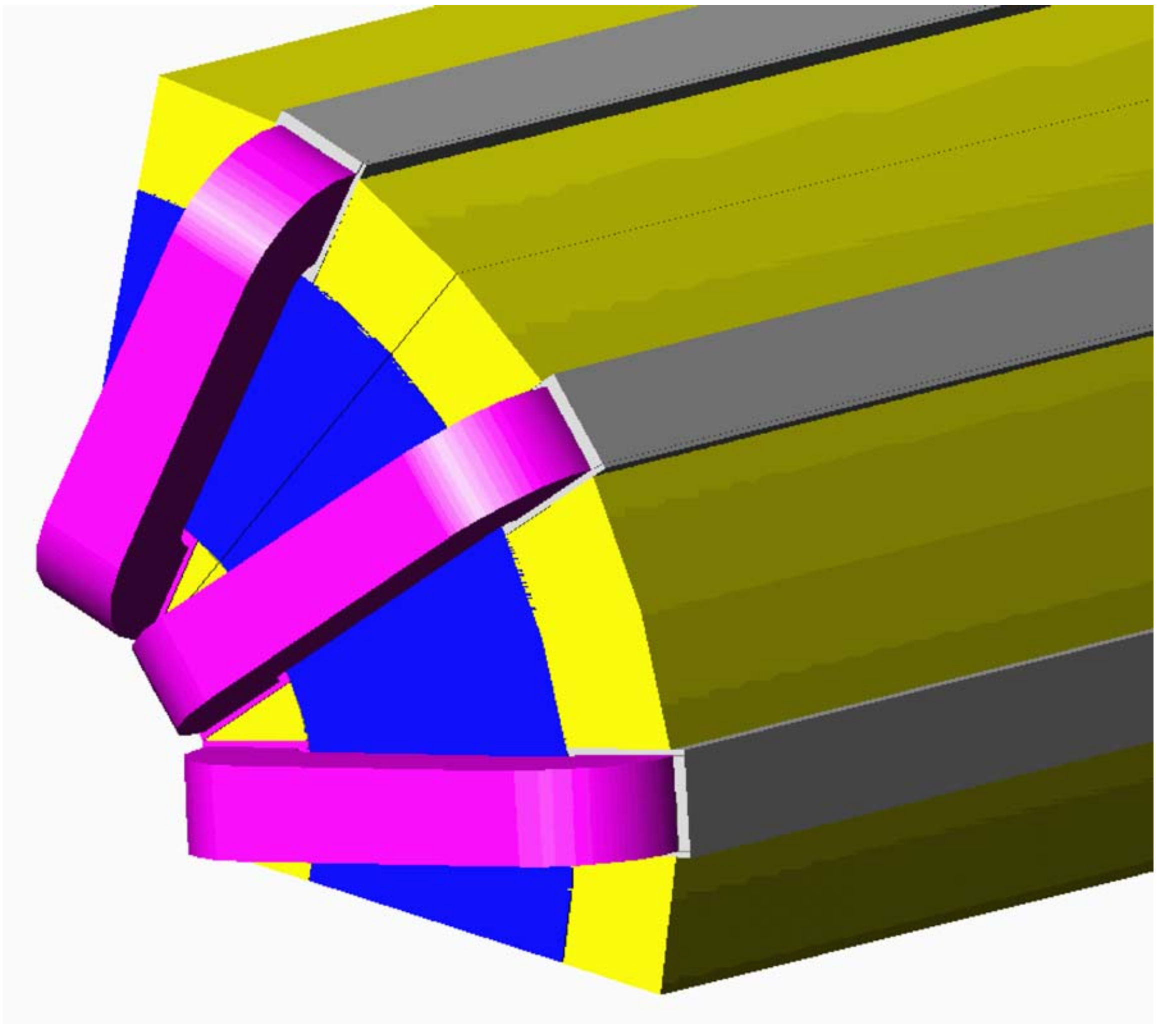

Fig.21 Three coils prototype

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